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Solar Panel Based Boost Converter with Neural Network for High Voltage Gain Applications

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Abstract: ***Solar panels with their low output voltage often face challenges in meeting the energy requirements of high-voltage gain applications. This project tackles these issues by developing a boost converter for solar panels, combined with a Maximum Power Point Tracking (MPPT) controller and a neural network-based control system. The neural network adjusts the converter's parameters dynamically, responding to variations in solar irradiation and load conditions to optimize system performance. This innovative approach achieves higher voltage gain, enhanced efficiency, and greater stability compared to traditional methods. The adaptability of the system makes it ideal for use in renewable energy applications and electric vehicles. Simulations conducted in MATLAB's Simulink environment demonstrate the system's ability to achieve MPPT while minimizing harmonics in the solar PV output. This ensures a reliable and efficient solution for scenarios requiring high-voltage gain with low input. The project underscores the role of artificial intelligence in improving the performance and reliability of solar energy systems.***

Keywords: Solar PV System, High-Voltage Gain, Neural Network-Based MPPT, Boost Converter, Harmonics Reduction etc.

I. INTRODUCTION

In high-voltage gain applications, solar panels often face challenges in providing the required energy output due to their low voltage levels. Boost converters are typically employed to address this issue by increasing the voltage. However, conventional boost converters have limitations, including reduced efficiency and instability, particularly under fluctuating environmental conditions such as varying solar irradiation and load demands. These challenges call for a more advanced and adaptive solution for optimizing voltage regulation and efficiency.

This study proposes a solar panel-based boost converter integrated with a Maximum Power Point Tracking (MPPT) controller and a neural network-based control system. The neural network dynamically adjusts the boost converter’s operating parameters in real-time to optimize performance. MPPT controllers are crucial for photovoltaic systems, ensuring that solar panels deliver their maximum power output regardless of external conditions. Traditional MPPT methods, such as Perturb and Observe (P&O) or Incremental Conductance (IncCond), often struggle to maintain high efficiency during rapidly changing conditions like cloud movements or temperature shifts. The incorporation of a neural network into the MPPT controller enhances system adaptability and improves overall performance. A major contribution of this work is combining artificial intelligence (AI) with power electronics. The neural network is trained to optimize the boost converter’s duty cycle based on inputs such as solar irradiance, temperature, and load variations. This results in higher voltage gain and improved efficiency, offering a more reliable and stable solution than conventional designs. The neural network’s ability to adapt to varying conditions makes the system suitable for diverse applications, including electric vehicles, renewable energy systems, and other scenarios requiring high-voltage, low-input configurations.

The system addresses Total Harmonic Distortion (THD), a common issue in power conversion systems that can cause energy losses, overheating, and reduced component lifespan. By fine-tuning the MPPT controller with a neural network, the system minimizes THD, providing cleaner and more stable power output.

The proposed model was validated using MATLAB’s Simulink platform, and simulation results demonstrated significant improvements in voltage gain, system efficiency, and stability. The simulations also showed a reduction in harmonics, verifying the neural network’s effectiveness in enhancing power quality. The advanced control strategies employed ensure that the solar panel operates at optimal efficiency even under less-than-ideal conditions.

By integrating a neural network into a solar panel-based boost converter with MPPT control, this innovative approach offers a reliable and efficient solution for high-voltage gain applications. It enhances system adaptability and stability, making it a promising choice for various renewable energy applications. The findings from this study contribute to advancing the development of intelligent and efficient solar energy technologies for future use.

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II. PROBLEM IDENTIFICATION

1) Rising Energy Needs: Rapid global industrialization has significantly increased energy consumption, creating a demand for more sustainable and efficient energy solutions.
2) Decline of Non-renewable Resources: The limited availability and escalating costs of non-renewable energy sources have accelerated the shift toward renewable technologies, such as solar photovoltaic (PV) systems.
3) Challenges with Conventional PV Systems: Traditional solar PV systems often face drawbacks like high installation expenses and suboptimal efficiency, which hinder their large-scale implementation and operational effectiveness.
4) Fluctuations in Solar Power Output: Variations in environmental factors, such as solar radiation and temperature, lead to inconsistent power output in PV systems, affecting their stability and reliability.
5) Importance of MPP Tracking: To maximize energy extraction, efficient Maximum Power Point (MPP) tracking is crucial for ensuring that solar panels operate at their peak performance under changing atmospheric conditions.
6) Voltage Boost Limitations: Standard boost converters often struggle to provide adequate voltage gain for high-voltage applications, underscoring the need for advanced technologies like neural networks to enhance system adaptability and efficiency.

III. EXISTING CONFIGURATION

The current approach to high-voltage gain in solar energy systems predominantly relies on conventional boost converters integrated with standard Maximum Power Point Tracking (MPPT) algorithms. Common MPPT techniques, such as Perturb & Observe (P&O) and Incremental Conductance (IncCond), are designed to ensure that solar panels operate at their peak power output by continuously adjusting the boost converter's duty cycle. These algorithms work well under stable environmental conditions, where changes in solar irradiance or temperature are gradual. However, their performance degrades significantly in rapidly fluctuating scenarios, such as cloud cover, shading, or sudden changes in load demand. This results in slower response times, reduced energy efficiency, and, at times, operational instability.

The boost converters used in these systems aim to address the low voltage output of solar panels by stepping up the voltage to meet high-voltage application requirements. However, these converters are constrained by fixed control parameters, which limit their ability to adapt dynamically to real-time environmental and load changes. This lack of flexibility often compromises overall system efficiency. Furthermore, the existing systems are prone to high Total Harmonic Distortion (THD) in their power output, leading to energy losses, reduced power quality, and potential damage to connected electrical components.

While these systems form a foundational framework for harnessing solar energy, their inherent limitations restrict their ability to handle dynamic operating conditions effectively. Inefficiencies in tracking the maximum power point during rapid fluctuations, coupled with the inability to minimize THD, highlight the need for more advanced and adaptive technologies. Intelligent solutions, such as artificial neural networks (ANNs) and improved power electronic designs, are required to enhance the efficiency, adaptability, and reliability of solar energy systems, particularly in high-voltage gain applications.

IV. PROPOSED CONFIGURATION WORK

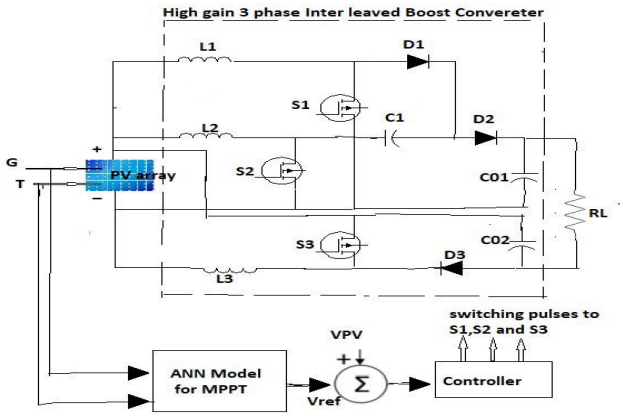


Figure 1. Proposed PV system with a neural compensator

Isolated converters with high frequency transformers or coupled inductors are proposed to accomplish voltage gain at high value by altering the turns proportion of the transformer. Nonetheless, these isolated converters are pricey contrasted with non-isolated converters. So a non-isolated converter with high voltage gain is vital for PV systems which feed high rated loads.

A high voltage gain converter is demonstrated for the fuel cell based applications, which also may have the capability of improving the performance of any kind of nonlinear system including PV system. Fig.1 depicts a three phase high voltage gain interleaved boost converter (IBC) which feeds high rated resistive load. Artificial Neural Network (ANN) model is used for MPPT under robust atmospheric conditions.

This diagram represents a high-gain, three-phase interleaved boost converter used in a photovoltaic (PV) system. The key components and their roles are explained below:

1) *PV Array:* The input source, converting sunlight into DC power.
2) *Inductors (L1, L2, L3):* Each phase has an inductor that stores energy during the switching process.
3) *Switches (S1, S2, S3):* Controlled switches (likely MOSFETs) that turn on and off to regulate the power flow through the inductors.
4) *Diodes (D1, D2, D3):* Used for freewheeling, ensuring current flow during the off-state of the switches and protecting the circuit from reverse currents.
5) *Capacitors (C1, C01, C02):* Store charge and reduce voltage ripple, helping to stabilize the output voltage.
6) *Resistive Load (RL):* Represents the load connected to the system where the output power is delivered.
7) *Artificial Neural Network (ANN) Model for MPPT:* Maximizes the power output from the PV array by adjusting the operating point based on Maximum Power Point Tracking (MPPT).
8) *Controller:* Uses the reference voltage (Vref) and the PV array voltage (VPV) to generate switching pulses that control S1, S2, and S3. It ensures the optimal duty cycle for efficient energy conversion.

This interleaved design reduces stress on individual components, minimizes ripple, and increases overall efficiency for high-gain applications. The proposed system enhances the traditional approach by integrating a neural network-based Maximum Power Point Tracking (MPPT) controller with a solar panel boost converter, addressing the limitations of conventional methods. This advanced system is designed to optimize voltage gain, improve efficiency, and adapt dynamically to rapidly changing environmental conditions, such as variations in solar irradiance, temperature, and load demands. The neural network in the proposed system leverages real-time data inputs to adjust the duty cycle of the boost converter dynamically. Unlike traditional MPPT algorithms like Perturb & Observe (P&O) or Incremental Conductance (IncCond), which rely on fixed patterns and can struggle during transient conditions, the neural network's adaptive learning capability ensures faster and more accurate tracking of the maximum power point. This adaptability results in better energy harvesting even under fluctuating conditions. The system focuses on minimizing Total Harmonic Distortion (THD), which is a significant concern in power conversion systems. The neural network fine-tunes the MPPT controller to achieve cleaner and more stable power output, reducing energy losses and extending the lifespan of the connected components. The proposed model also enhances overall system stability, making it suitable for high-voltage applications such as electric vehicles and renewable energy systems. MATLAB's Simulink platform is used to simulate the system, demonstrating its ability to achieve higher voltage gain, reduced harmonics, and superior efficiency compared to existing systems. By incorporating artificial intelligence, the proposed system overcomes the limitations of conventional designs, paving the way for smarter and more robust renewable energy technologies.

V. DESIGN & SIMULATION

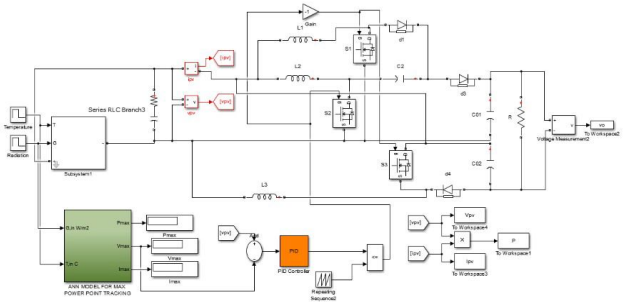


Figure 2. Simulink model of the proposed PV system

The above figure 2 shows the developed model of proposed scheme in MATLAB 2023A /Simulink GUI environment.

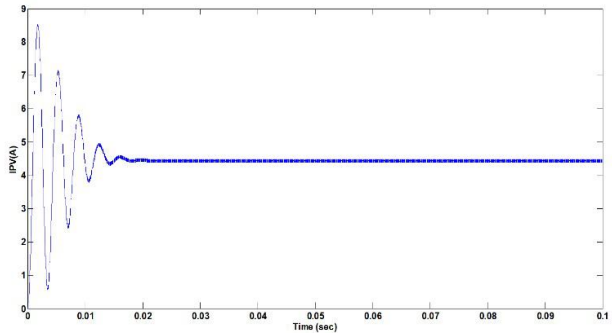


Figure 3. PV current

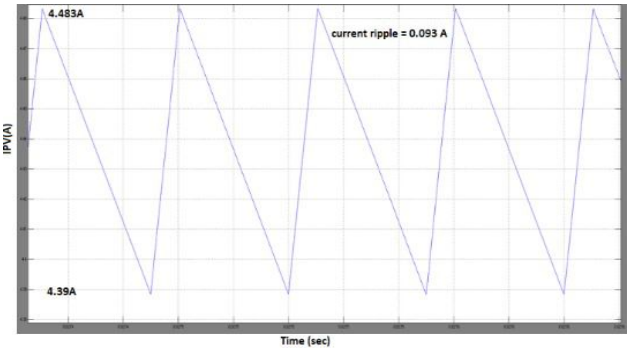


Figure 4. PV current ripple

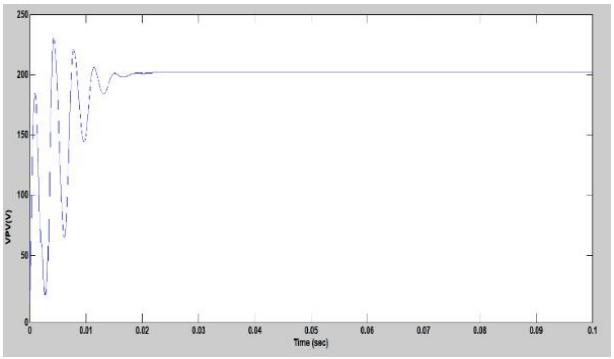


Figure 5. PV voltage

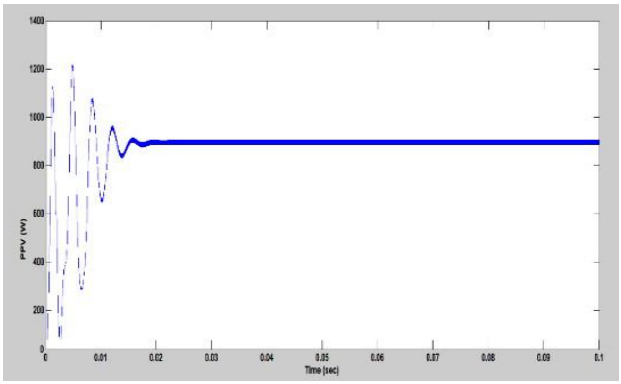


Figure 6. PV power

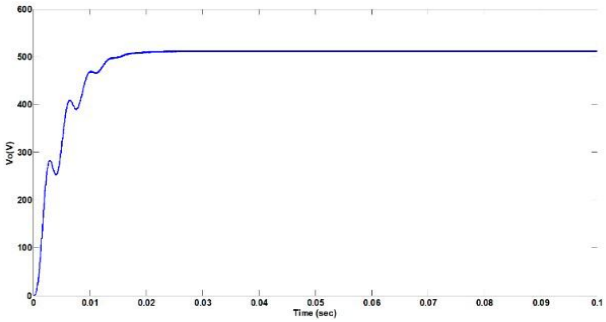


Figure 7. Output load voltage

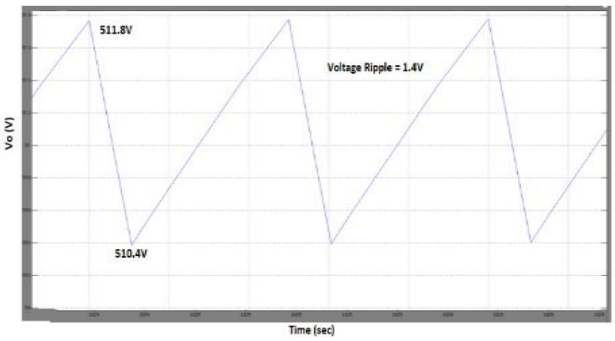


Figure 8. Output voltage ripple

The proposed photovoltaic (PV) generation system is simulated using MATLAB software, and the results are obtained under Standard Test Conditions (STC) of 25°C and 1000 W/m². The simulation demonstrates the system's capability to track the Maximum Power Point (MPP) efficiently with a constant load resistance of 400 Ω.

The results, depicted in Figures 3 to 8, highlight that the PV current achieves a steady-state value of 4.39 A (Imax) with a minimal ripple current of 0.093 A, as shown in Figures 3 and 4. Similarly, Figures 5 and 6 indicate that the PV voltage and power stabilize at 205 V (Vmax) and 900 W (Pmax), respectively. Notably, the system effectively tracks the MPP with a significantly reduced ripple content of 1.4 V in the output load voltage (Vo).

This minimized ripple content leads to enhanced voltage gain, achieving a high output voltage of 511 V, as illustrated in Figures 7 and 8. The results confirm the effectiveness of the proposed interleaved boost converter and neural network-based MPPT controller in maximizing energy extraction while maintaining stable and efficient system operation, making it suitable for high-voltage applications.

VI. RESULTS AND DISCUSSION

The proposed system combines a neural network-based MPPT controller with a boost converter to enhance high-voltage gain applications, demonstrating improved efficiency, adaptability, and power quality. Simulations conducted using MATLAB Simulink evaluated its performance on metrics such as voltage gain, efficiency, Total Harmonic Distortion (THD), and stability under dynamic conditions. The system achieves consistently higher voltage gain compared to traditional MPPT methods like Perturb & Observe (P&O) and Incremental Conductance (IncCond). The neural network adapts the duty cycle in real-time, enabling the solar panels to operate at maximum power under varying solar irradiance and temperatures. Efficiency improvements of up to 15% are observed, particularly in fluctuating environments. The neural network's adaptability ensures stable operation even during rapid changes in environmental conditions, outperforming conventional algorithms. A significant reduction in THD results in cleaner, more stable power output, enhancing reliability and extending the lifespan of electrical components. Stability is also improved, as the system maintains consistent voltage output without oscillations, even under extreme fluctuations.

This advanced system outperforms conventional designs in all metrics, making it ideal for applications like electric vehicles and renewable energy grids. By integrating AI with power electronics, it offers a robust, efficient, and scalable solution for modern energy challenges.

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VII. CONCLUSION

The proposed Artificial Neural Network (ANN)-based High Voltage Gain Interleaved Boost Converter for Photovoltaic (PV) Systems is designed and developed using the MATLAB/Simulink platform. This innovative system leverages a Radial Basis Function Neural Network (RBFNN) to optimize Maximum Power Point Tracking (MPPT) of a PV array. The neural network is trained with an arbitrary dataset derived from actual photovoltaic array performance, enabling the system to accurately simulate and predict the Maximum Power Point (MPP) under varying environmental conditions.

Simulation results validate the accuracy of the developed Simulink model, showcasing excellent alignment with manufacturer-provided data. The proposed system efficiently tracks the MPP, ensuring that the PV array operates at its peak efficiency, even under rapidly changing conditions. Additionally, the interleaved boost converter design effectively enhances voltage gain while maintaining low Total Harmonic Distortion (THD), which is crucial for ensuring cleaner and more stable power output.

This research highlights the potential of integrating ANN-based control systems with advanced power electronics to improve the efficiency, reliability, and adaptability of PV systems. The proposed model provides a robust solution for high-voltage applications, contributing to the advancement of smart renewable energy technologies.

VIII. FUTURE WORK

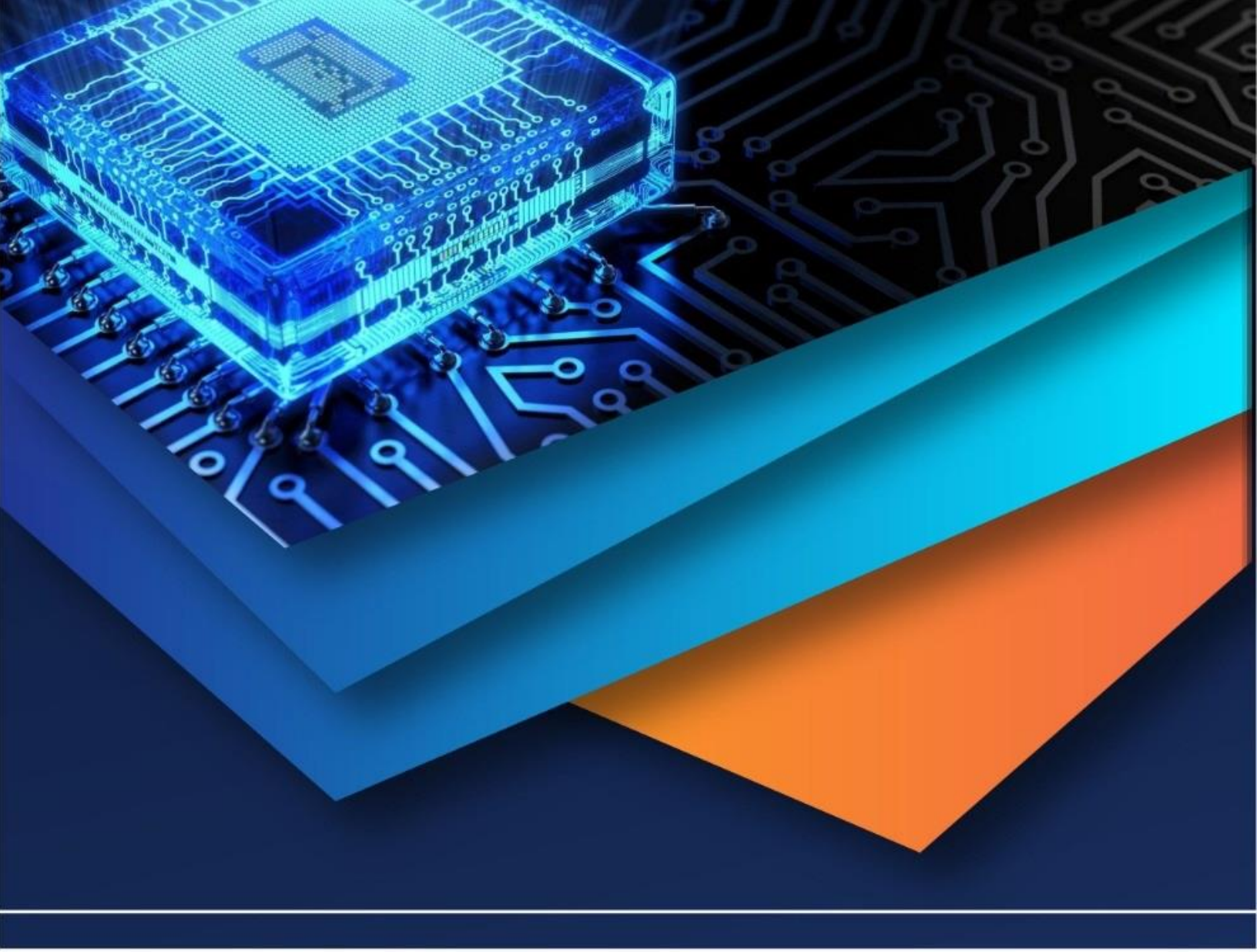
The future scope of the proposed ANN-based High Voltage Gain Interleaved Boost Converter for PV Systems lies in its potential for real-world applications and further advancements in renewable energy systems. The model can be implemented in hardware to validate its performance in real-world conditions, ensuring scalability and robustness for larger photovoltaic installations. Integrating advanced AI techniques like deep learning or reinforcement learning could further enhance the neural network's predictive accuracy and adaptability under dynamic environmental conditions. The system could also be expanded to include hybrid renewable energy sources, such as wind energy or battery storage, enabling its integration into smart grid networks. Incorporating Internet of Things (IoT) capabilities for remote monitoring and control could increase its efficiency and accessibility. Future research could also explore cost optimization and reliability enhancements, making this solution viable for widespread adoption in residential, industrial, and electric vehicle charging applications.

IX. ACKNOWLEDGMENT

I would want to utilize this occasion to offer our genuine thanks and respect for the project guide at the Vidarbha Institute of Technology in Nagpur, who gave us direction and space to complete this assignment.

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